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Some Philosophical Aspects of Particle Physics

1. Introduction

1. Why should philosophers of science be encouraged to take an interest in particle physics?
- Answer:- (a) Subject abounds in technical jargon, names & classification of several hundred particles
- (b) Characteristically theories in particle physics require rather elaborate mathematical development before any "practical" calculations could be carried out.
- (c) The literature of the subject is very extensive (amount published since 1930 exceeds publications prior to 1930 in all branches of physics)

2. Relevance of particle physics to Philosophy of Science

- (a) Ept is a modern ^{live} branch of physics. Philosophy of science often deals with examples which are no longer of current interest in science. Galileo & Newton or even non-relativistic quantum mechanics. For this reason physicists tend to feel philosophy of science is somewhat irrelevant - particularly since the character of theoretical physics appears to be significantly different from what it was in many of the historical examples. The study of Ept gives an excellent opportunity of examining the truth of this claim.

(b) opt is in a state of Kuhnian "crisis".
 Such paradigms or events are generally
 regarded as inadequate. Of one
 regards "normal" science as philosophically
 rather dull, following Popper, then
 the study of a "crisis" situation as
 it happens should be of considerable
 interest to philosophers of science.

(c) opt thus provides an ideal testing
 ground for theories of how science
 develops. we can look at:—

(1) Methodologies of Linguistics, how
 successive theories are as a matter
 of historical fact, logically related to
 one another is. Correspondence relations
 between theories. There is also the
 normative/perceptive sense of specifying
 roles of discovery or heuristics
 strategies, which may themselves
 be derived from the decriptive
 historical analysis

(2) Methodologies of Appraisal, how
 we appraise a theory once it
 has, for whatever reason and by
 whatever heuristic process, been
 proposed. This appraisal typically
 involves consideration of

- (1) simplicity, single unifying theory
- (2) empirical content, falsifiability
- (3) inferential truth content, the degree
 to which a theory encompasses ^{correctly} a large
 number of facts.

- 8 Novel predictions of S-matrix theory include (1) forward scattering dispersion relations
(2) Regge trajectories for classifying particles and understanding their properties.
(3) understanding of inelastic reactions (Mandelstam)

(4) The degree to which we believe the theory to be true - this is connected particularly with the idea of successful novel predictions

Appraisal will involve discerning relation of theory to experiment which involves the following points

- (1) Novel predictions which guide* experimental discoveries such as antiproton, K^0 regeneration, Ω^- and neutrons.
- (2) Novel predictions which are verified "serendipitously" such as the positron and Yukawa's meson.
- (3) Crucial experiments whose success has given great impetus to a theory as e.g. Lamb-shift or Ω^- .
- (4) The computational gap which may make a theory "insulate" it from experimental tests.

(d) In a reductionist programme the aim is to see as a foundation for the whole hierarchical structure e.g. biology + chemistry \rightarrow physics \rightarrow etc.

But if "this" foundation is itself shaky does this throw doubts on the whole programme. Also the reductionist programme depends essentially on explaining

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Complex phenomena in terms of simple phenomena but there are indications in the bootstrap philosophy that ~~the~~ ^{the} simplest objects involve for their understanding consideration of complex objects. So in a sense the reductionist programme may be seen as circular thus
Complex \rightarrow simple \rightarrow complex.

Another possibility is an open-ended infinite regress in which every elementary particle is itself resolved by more delicate probing into further constituents.

At all events the idea of rooting with elementary particle physics reached a stable bedrock foundation for a reductionist programme seems to be illusory.

- (e) This leads us to pose the question. What light does left throw on the ultimate nature of matter? Is the alternative programme still a valid one? Or should we subscribe to a bootstrap philosophy, or to Heisenberg's view of a unified field or candidate for an Aristotelian fundamentalism?

(F) Topics not discussed

- (1) Role of symmetry in elementary particle theory. Ever since decisive role of symmetry constraints in deriving new theories was emphasized by ~~Einstein~~ Einstein in the development of special relativity in 1905, the same idea of deriving theories from symmetries instead of symmetries from theories has played a major role in particle physics. Examples are charge independence as expressed in the isotopic spin formalism of Heisenberg (1932), the introduction of the 'strangeness' quantum number by Gell-Mann and Nishijima (1953-1955), the discovery of non-conservation of parity in weak interactions suggested by Lee & Yang in 1956, the $SU(3)$ symmetry classification of hadrons by Gell-Mann & Ne'eman in 1961, and the extension to $SU(6)$ by Gilkey & Rodicatti and by Saketa in 1964.

But we can also regard symmetry as interesting properties derived from fundamental laws. We shall be concerned with attempts at spelling out the detailed dynamical laws, although in practice there always involves taking certain symmetry considerations into account.

At all events the subject of symmetry has been treated in a separate paper "Symmetry in Intertory Relations" (1975)

- (2) Basic philosophical problems avoided with quantum mechanics, such as the theory of measurement, and how these problems look in the light of developments we shall be discussing which have taken place within the general context of quantum mechanical ideas. For our purposes we shall adopt a naive "fluctuation" view of quantum aspects i.e. observables as subject to quantum fluctuations. This view is not tenable in any simple sense but it will suffice for our purposes.

- (3) Ontological status of elementary particles. We shall not discuss directly the question of whether the ~~view~~ "ultimate" view of matter provided by QFT is more "real" than the former objects of our experience (cf. Eddington's two tables). We shall actually assume a realist approach to the interpretation of physical theories with due remarks on the notion of surplus mathematical structure

* name ploten due to C. H. Lewis (1926)

2. History of theoretical developments in elementary Particle Physics

We divide the history of ept into four main decades:—

Dirac 1927 Relativistic Quantum Field Theory

Feynman 1947 Renormalization
↳ Feynman diagram techniques

Landau 1958. The Analytic S-Matrix
↳ Bootstrap hypothesis

Witten 1967 Revival of field theories
↳ gauge theories
non-local theories
(strings and bags)

Around 1927 the candidates for the elementary particles were the electron (discovered in 1897), the proton (1913, Moseley's study of 'X-ray spectra') and the photon (Einstein, 1905)*. Quantum Mechanics (Heisenberg 1925) and wave mechanics (Schrödinger 1926) were early attempts to provide a theory of the electron (and less interestingly the proton).

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but our story of the history of characteristically
elementary particle theories will start
with attempts to incorporate the
photon in the new theoretical framework.

The reason why the photon is
more typical than the electron
or the proton of the many particles
later to be discussed is the
fact that photons can be produced
(i.e. emitted) and can annihilated (i.e.
absorbed) so in general we want
a theory that allows for a
variable number of particles.

Now most of the elementary
particles are spontaneously unstable,
i.e. they disappear & decay
after a very short time (even
without interacting with an "observer")

so clearly a theory which can
deal with the photon is likely
to be able to accommodate the
description of the essentially permanent
character of elementary particles.

The reason why this aspect
of the theory does not surprise
on elementary atomic or molecular
physics is that the electron
and proton are stable against
spontaneous decay.

The appropriate methods for describing
the spontaneous and discontinuous
of particles turned out to be
relativistic quantum field theory.

(1) Relativistic Quantum Field Theory

1. Two ingredients in RQFT

This is the application of ideas from relativity and quantum mechanics to the dynamics of fields i.e. systems with infinitely many degrees of freedom.

Relativity had demonstrated equivalence of mass and energy expressed as $E = mc^2$.

This suggests that even for a particle at rest its rest mass m_0 might be interconvertible with energy of amount $m_0 c^2$. So in a relativistic theory we expect possibility that particles of rest mass m_0 can be created by suitable input of energy with a threshold $m_0 c^2$. Similarly annihilation of a particle may be possible with release of this amount of energy.

Quantum theory now allows for energy fluctuations ΔE in system related to life time Δt of the quantum state of the system by the Uncertainty relation $\Delta E \Delta t \sim \hbar$. So creation of a particle is possible provided particles annihilate with an time of order $\hbar / m_0 c^2$ (i.e. after travelling a distance of $\sim \hbar / m_0 c$). Particles produced in this way by spontaneous quantum fluctuations are called virtual particles.

Consequence is that in RQFT every problem (even the N-body problem i.e. the vacuum) becomes a many body problem.

2. Two routes to RQFT formalism

(a) Field quantization Ehrenfest
Debye ^{Ehrenfest} (1910) following suggestion of Debye (1906)

suggested derived Planck's radiation law by quantizing motion of the oscillators represented by the normal modes of the radiation field itself. Heisenberg's matrix mechanics was immediately applied to the same problem. by Jordan (Born & Jordan (1925) Heisenberg, Born & Jordan (1926)).

A quite different approach was to start with the particle concept and derive Planck's law by regarding radiation as a gas of photons subject to the quantum statistics. This was the approach of Bose (1924). But neither Bose nor Debye (and later Jordan) derived the detailed dynamical process involved in radiation and absorption. ~~The earlier~~ ~~had been provided~~ the framework for such a detailed approach had been laid by Einstein in 1917 with his theory of spontaneous and induced radiation probabilities, the so called A and B coefficients, but it remained for Dirac in 1927 to clarify 1) the relationship between the Debye and Bose approaches, 2) to actually provide a theoretical basis for calculating the Einstein coefficients. In particular what was the perturbing influence that caused spontaneous emission (the A coefficient)?

Dirac showed that we could treat the radiation field in two distinct ways and arrive at the same final result a quantized field, which united and transcended

Note that first quartzized field in
second quartzization refers to
1-footed S. Eq. — These can
second-quartzization. The field
in 4 complex S. field unlike the
real e-n. field which is
related to quartzization in the
method of first-quartzization

the wave and particle pictures of light (cf Bohr's Complementarity view that the wave and particle pictures are alternatives applicable in complementary situations)

Field quantization

classical field $\xrightarrow{\text{field quantization}}$ Quantized Field

Second Quantization

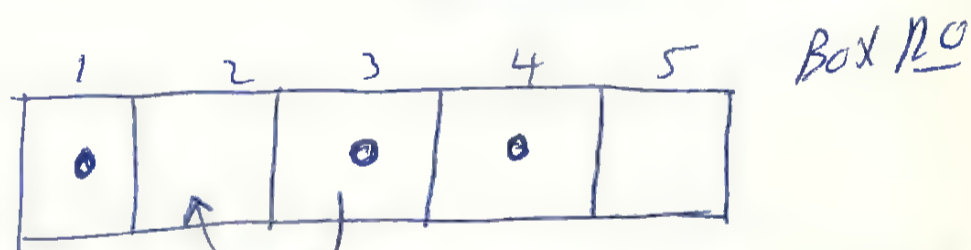
N classical particles $\xrightarrow{1^{\text{st}} \text{ quantization}}$ N -particle Schrödinger eqn
 $\xrightarrow{2^{\text{nd}} \text{ quantization}}$ Quantized Field.

#

3 - Fock formalism

We explain the significance of second quantization using the ideas of Fock (1932) although the needed is implicit in Dirac's 1927 paper.

We represent an N -particle state by locating each particle in a particular one-particle state

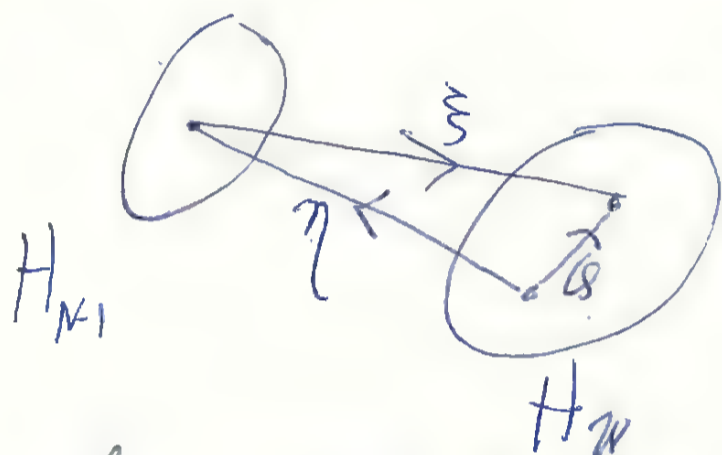


An operator in the N -particle Hilbert space H_N acts by switching particles from one state to another e.g. particle in box 3 \rightarrow box 2. But this can be thought of as a two stage process

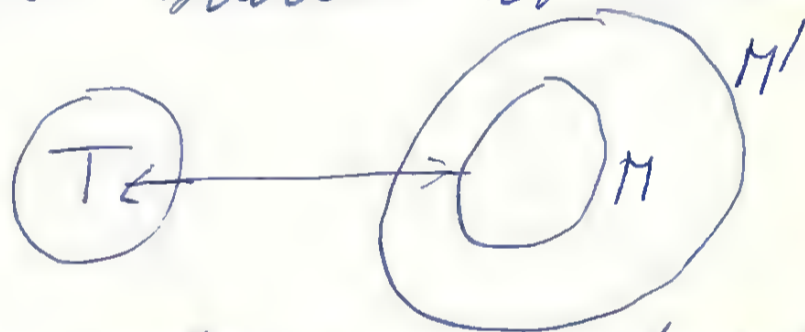
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 then Particle comes out of box 3 leaving 2 particles only
 Particle is put into box 2 so we can again have
 3 particles in all.

Schematically we introduce an operator η
 which takes a particle out of a box
 and an operator ξ which puts it back
 in (in general) another box.

So we "factorize" the whole operator denoted by
 Q as $Q = \xi \eta$



So we have introduced H_{N-1} as an element
 of surplus structure in our theory
 H_N .



In general we then now add with
 a Fock space $H = H_0 + H_1 + H_2 + \dots$

but so long as we restrict ourselves to
 operators like $\xi \eta$ the Fock space is a mere
 mathematical device. But now the
 formalism can be extended very easily
 to describe creation & annihilation

Note: Reformulation involves a change in
surplus structure
Sketches reveal evidence that
~~are~~ giving ontological reference to
some of the new surplus structure
(i.e. a realistic interpretation) of Zahar (1973)

Note: Paradigm shifts may involve a
correspondence relation but ontology
may be changed — compare
Watkins (1978) notion of revolutionary
reduction. (I prefer my revolutionary correspondence)

The correspondence relation involved
in sketches is a case of
radical reduction in Watkins's
terminology (or radical correspondence)

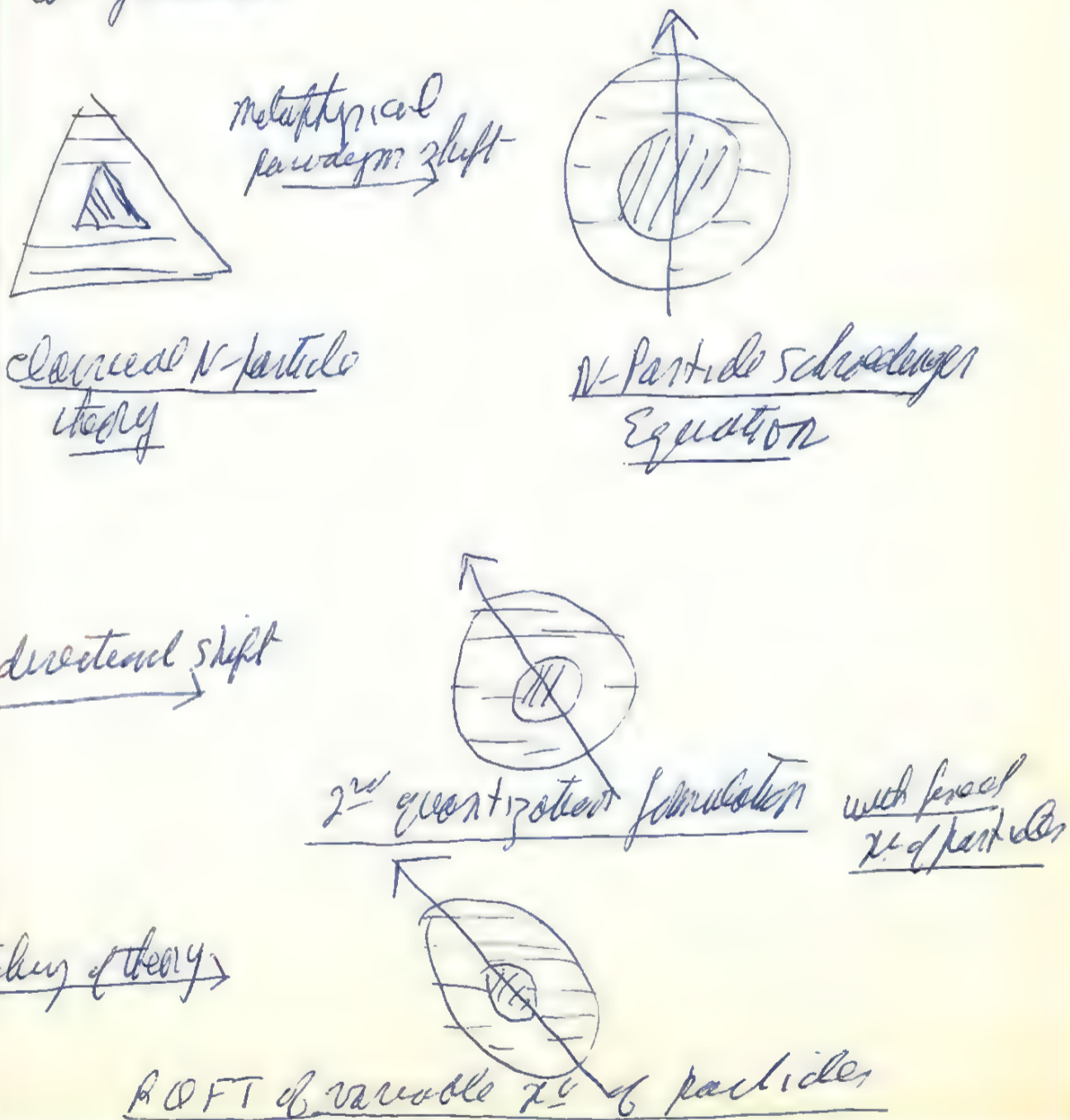
Note Watkins' reduction relation etc
are where theoretical structures (or content)
of old theory is by-passed

of particles. For example we might introduce an operator $\xi + \eta$ which would admit both processes.

Such linear combinations of "square root" operators are known as quantized fields and can also be introduced by directly "quantizing" the field amplitudes (electromagnetic potentials) which is the second method of approach.

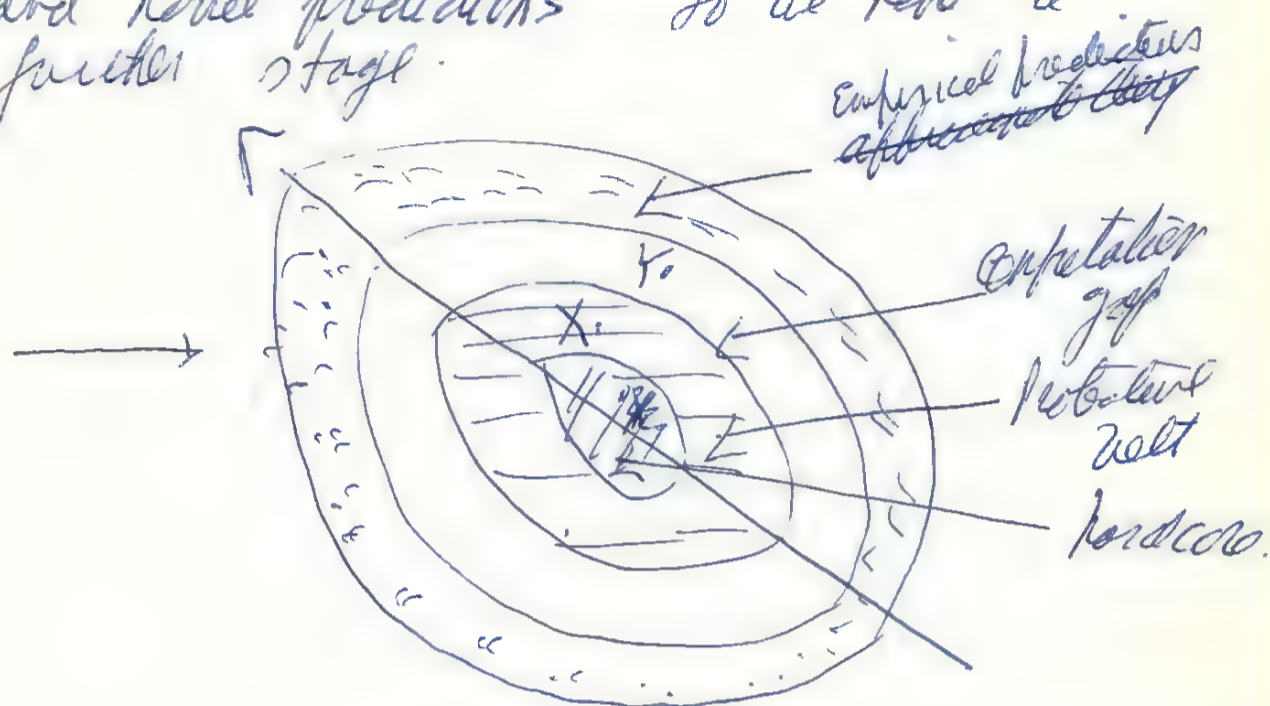
4. Reformulation and Sketching

We can represent the heuristic strategy involved as follows:



(Compare development of wave mechanics with
Hamiltonian formulation of classical mechanics
in terms of his characteristic function.)

But any new theory must be calculated
with to produce testable consequences
and novel predictions so we have a
further stage.



We can produce an approximate theory
in two ways.

- (1) alteration at x to produce solvable
model i.e. for model computational gap
is eliminated, not a model as refers
to as Model₁.
- (2) alteration at y to produce a
different scheme of approximation
this is also often referred to
as working with a model which
we designate as Model₂

Model₁ can be regarded as a special case
of Model₂ in which change of x is regarded as being
"moral" i.e. computational gap, but in practice
distinction between Model₁ and Model₂ is usually
clear.

(2)

Renormalization1. Divergences in Quantum field theory.

Dirac's theory was in a sense still born.

Ehrenfest pointed out that divergences would arise if the theory was used to calculate radiative reaction effects as occurs already in the classical theory with point electrons.

In 1930 Walker worked out the self-energy of the electron and found a quadratic divergence, so the situation is actually more serious in quantum theory than in classical theory where the self-energy is linearly divergent.

Indeed if one takes the theory seriously and calculates any quantity beyond the first non-vanishing order of perturbation theory one obtains infinite results. The situation is rather like set theory and the paradoxes.

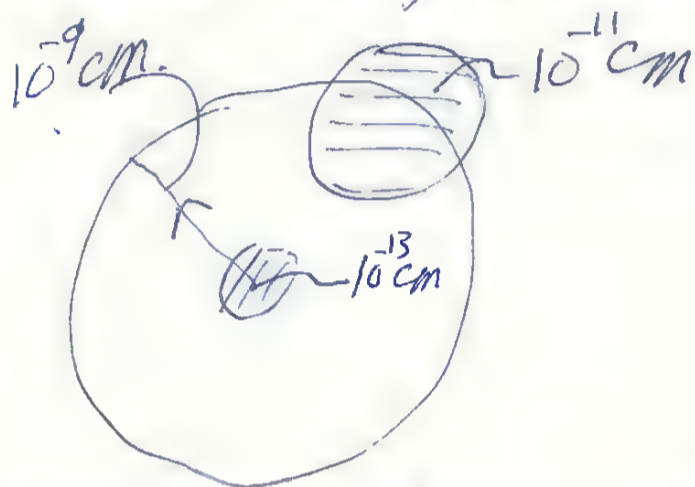
One can use "naive" set theory while knowing that the whole theory is actually inconsistent. The patching-up operation of Feynman's theory of T-operators can be compared with the Renormalization programme for dealing with the divergences.

The extra complication introduced by quantum theory is the effect of forced oscillations of the electron under the influence of the vacuum fluctuations of the field.

This contributes to the self-energy of the electron over and above the classical effect arising from the interaction of the electron with its own electric & magnetic field.

The self-energy problem is ameliorated but not eliminated in the theory, the

self-energy divergence being only logarithmic (Weisskopf (1934)). The effect of hole theory is to "smear" the charge distribution of the electron over a distance of order \hbar/mc due to ~~the~~ the onset of Pauli repulsion as the virtual pairs produced by vacuum fluctuations in charge and current density of the electron field. The vacuum field fluctuations now interact with the extended charge distribution.



(This is a separate effect from the polarization of the vacuum by the electron's own electric field which produces an infinite effective charge, together with a finite effect modifying the Coulomb force between two charges (Veltman (1975)).

2. classical renormalization

To deal with these infinities it may be suggested that the infinite contributions are absorbed into the definition of the mass and charge of the electron. The renormalized values being equated with the experimental values.

To see how this works in classical electrodynamics consider the equation of motion for an electron under the action of its own field.

Lorentz showed we could write

$$m \ddot{\mathbf{r}} = \mathbf{K}^{(0)} + \mathbf{K}^{(1)} + \dots$$

$$\text{where } \mathbf{K}^{(0)} = -\frac{2}{3} \frac{e^2}{\epsilon_0 c^2} \ddot{\mathbf{r}}, \quad d \approx 1$$

$$\mathbf{K}^{(1)} = \frac{2}{3} \frac{e^2}{c^3} \dddot{\mathbf{r}} \quad \text{etc.}$$

$$\therefore m \ddot{\mathbf{r}} = \mathbf{K}^{(1)} + O(\epsilon)$$

$$m' = m + \frac{2}{3} \frac{e^2}{\epsilon_0 c^2}$$

We now identify m' with experimental mass and also let $\epsilon \rightarrow 0$, when we have the finite equation

$$m' \ddot{\mathbf{r}} = \frac{2}{3} \frac{e^2}{c^3} \dddot{\mathbf{r}}$$

This approach to divergences in classical electrodynamics was suggested by Kramers in 1938 and was applied to the infinities of quantum theory. The divergences of quantum theory were suggested by Kramers and his ideas were used by Bethe to provide an explanation for the Lamb shift in the hydrogen spectrum (Lamb-Retherford 1947).

3. Role of Lorentz invariance for unambiguous subtraction of infinite quantities

The problem now was to show that an unambiguous subtraction procedure could be defined in which infinite contributions from all orders of perturbation theory could be consistently absorbed in renormalization of mass and charge of the electron.

But in general subtraction of infinite quantities is entirely ambiguous. To obtain a unique result, agreeing with what one would expect from a "finite" theory it was necessary to formulate the subtraction procedure in a manifestly Lorentz invariant manner. To see how this helps in the subtraction problem, consider as a simple example, evaluating

$$I = \int_{-a}^a x dx = \frac{1}{2} (a^2 - a^2)$$

Lim I is quite ambiguous, e.g. with $a = d \rightarrow \infty$, $I = 0$, but with $a = b - 1/b \rightarrow \infty$, $I = 1$ or so on. I is only conditionally convergent but for a finite theory, integrals would behave "properly" at infinity and value of I would then be zero (cf. e.g. $I = \int_0^b x e^{-x^2} dx = \frac{1}{2} [e^{-a^2} - e^{-b^2}] \rightarrow 0$ as $b \rightarrow \infty$).

But we can infer correct value $I = 0$ by specifying that that region of integration is symmetric with respect to rapidly decreasing $x \rightarrow -x$ which enforces the correct value $I = 0$.

#

quotation from Feynman

"By formulating the Hamiltonian method,
the wedding of relativity and
quantum mechanics can be accomplished
most naturally".

It is the kind of argument used to do
 resolve ambiguities in interpreting experimental
 quantities in the relativistic response.

The relativistic response manifestly
 consistent formulation of QED was
 first provided independently by Tomonaga
 and Schwinger but their approach was
 soon superseded by the ideas of Feynman
 (1949) with his space-time approach to
 Q.E.D.

(3) Feynman Diagrams

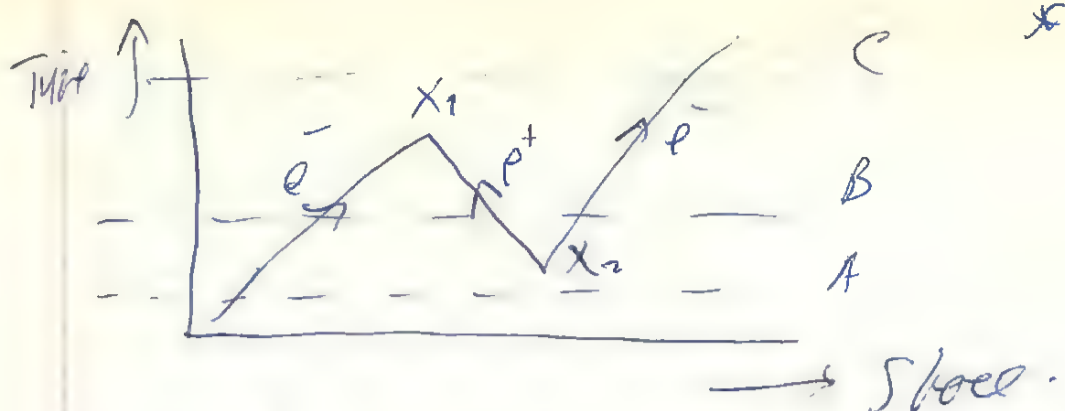
1. Feynman's Space-Time formulation of QED

This theory was derived from Feynman's
 reformulation of non-relativistic QM in
 terms of path-integrals (1948) and
 was extended to Q.E.D. in 1949.

The equivalence of Feynman's method
 with the Schwinger-Tomonaga
 approach was demonstrated by
 Dyson (1949). Feynman contrasts
 his approach with the traditional
 Hamiltonian approach which considers
 a scattering process for example in
 terms of successive time-slices of the
 total space-time history of the
 particle. * Consider for example a
 process of pair creation and annihilation
 described in second order perturbation theory
 by the conventional formalism.

* Quotation from Foreman

"It is as though a bird were flying low over a road suddenly see the road and it only when two of them come together and disappear again that he realizes that he has simply passed over a long straight road and a single road."

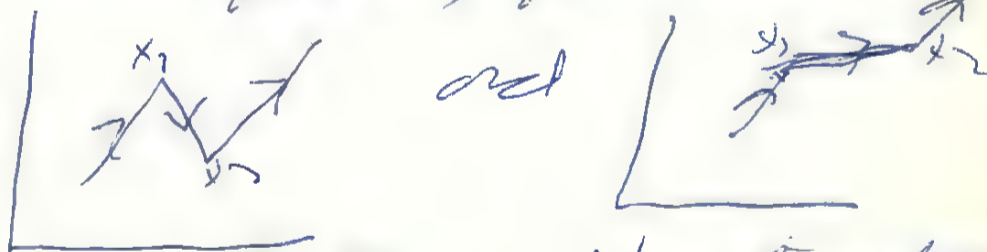


Consider 3 time slices at A, B & C.
 At A there are no particles
 B there are two particles
 C there are no particles again
 We describe this by saying a pair of particles is created at x_2 and one of the pair then created annihilates the remaining particle at x_1 .
 Feynman draws the diagram this:—



and says a single electron moves along a continuous trajectory in space-time
 — between x_1 and x_2 it propagates backward in time and negative energy.

To obtain total effect of all possible paths Feynman integrates over all x_1, x_2 , over places, processes like



on an equal footing. The integration being four-dimensional denotes the manifest Lorentz covariance of

* Compare Salam quotation
"An adequate relation is one which
is ^{con-}scious and intelligible to at least
two persons, one of whom may be the
other."

the formalism. The goal is to deal with the renormalization program. But also there is an enormous contribution towards closing the computational gap since processes which are apparently unrelated in old formalism are now all combined together in a single calculation.

2. Closing the Computational Gap

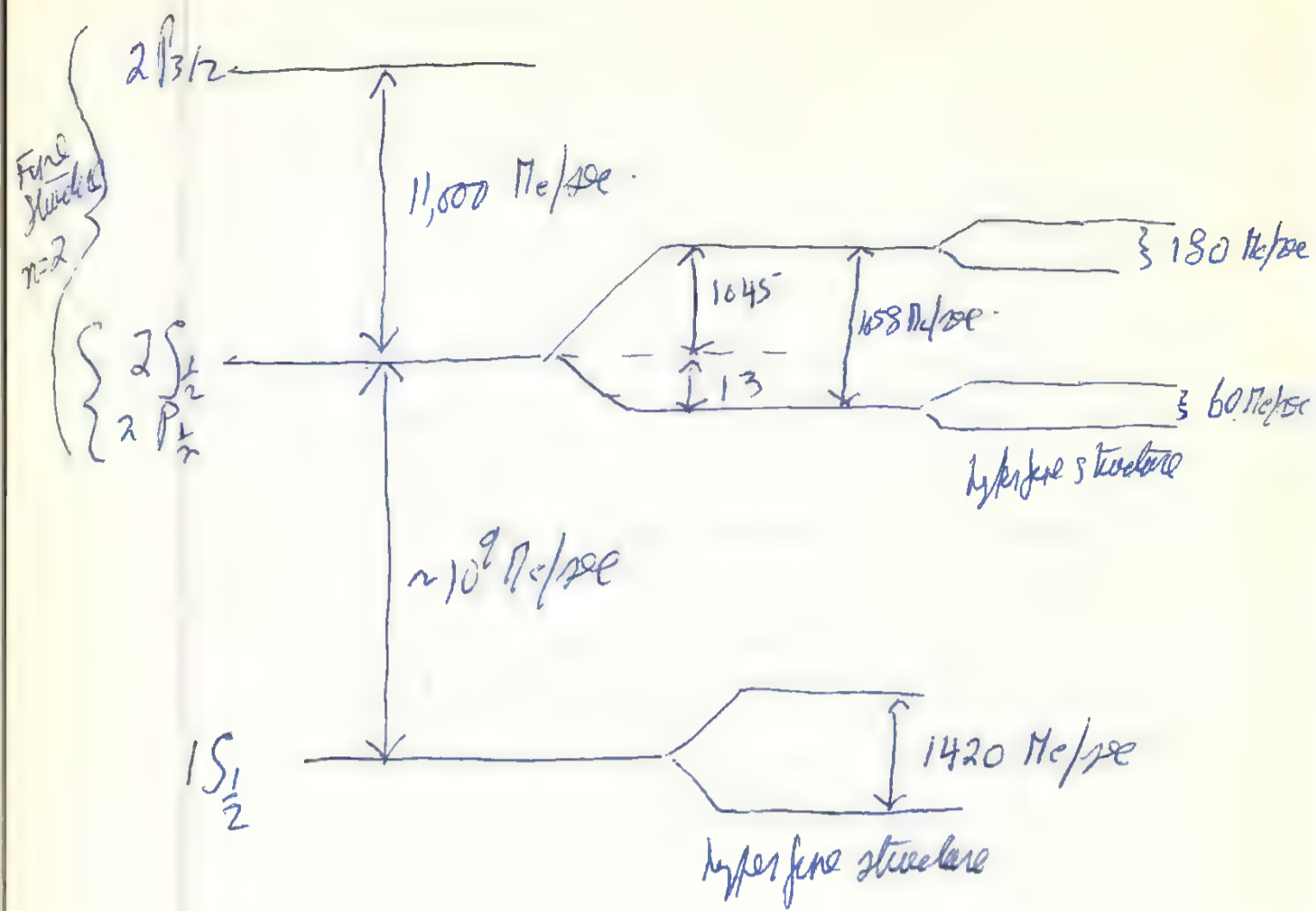
Another very important feature of the Feynman formalism is an enormous contribution it makes to closing the computational gap since processes which are apparently unrelated in the old formalism are now all combined together in a single calculation.

This had (i) a theoretical advantage:

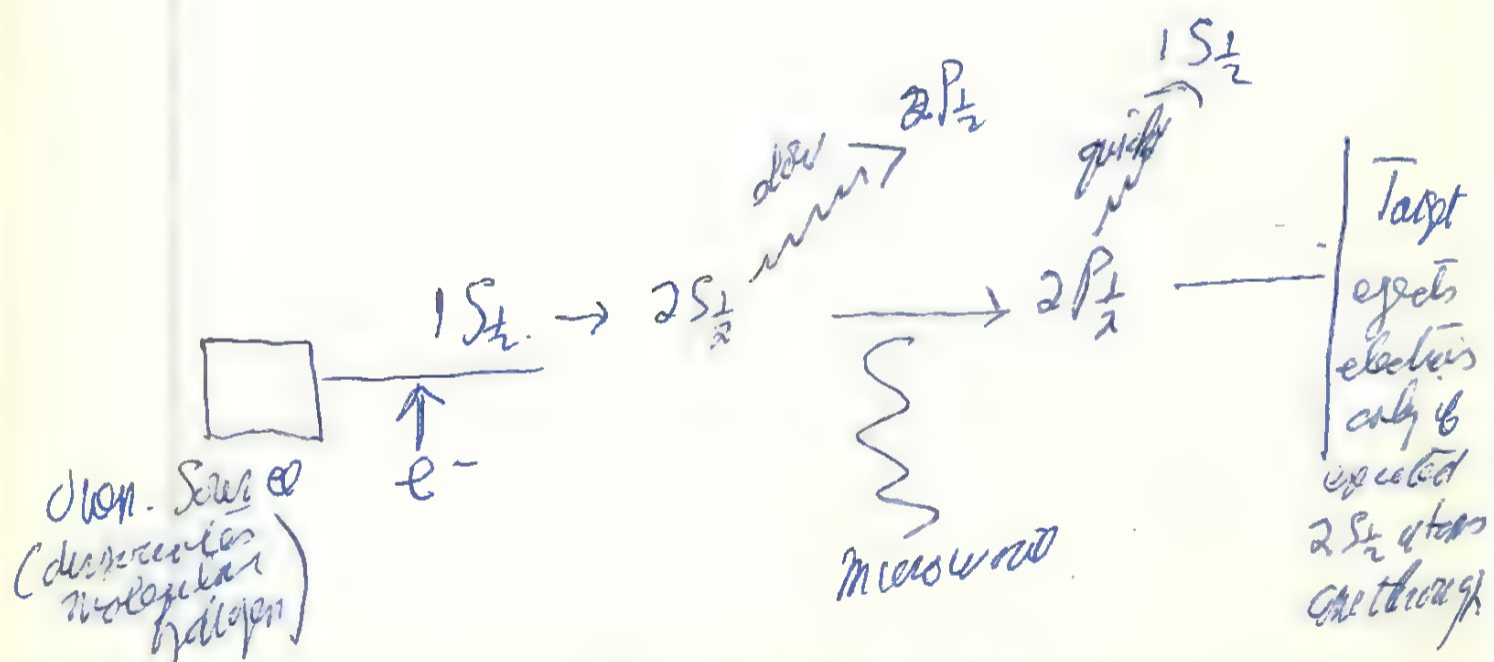
It enabled Dyson (1949) to handle the very complicated part of the renormalization of Q.E.D. to all orders of perturbation theory. (The gaps in the proof were filled in different ways by Ward & Salam in 1951)

(ii) a practical advantage

Higher order perturbation calculations (the so-called radiative corrections) can now be investigated by calculation which are still very complicated but not prohibitively so. Thus Schwinger (1948) worked out the second order corrections to the



Hydrogen spectrum



Lamb. Retherford experiment

Compton scattering of an electron, while in 1952 Brueckner & Feynman obtained the fourth order corrections to the scattering of a photon by an electron (Compton scattering) and in 1953 Schwinger solved the same problem for the scattering of an electron by an electron and of a positron by an electron.

4.3. The Lamb shift and the anomalous magnetic moment of the electron

But the most spectacular success of the new theory was the calculation of the Lamb shift and the anomalous magnetic moment of the electron.

(1) Lamb shift

Spectroscopic evidence for anomalies in the fine structure of the hydrogen spectrum (doublet) date back to Drayton (1926) — Porter (1938) interpreted anomalies in terms of an upward displacement of 2S level of about 1000 Mc/sec. (vacuum polarization calculation of Uehling (1935) was of wrong sign and too small by a factor of ten to explain the shift)

But Drinkwater, Richardson & Williams (1940) found no significant departure from the prediction of the Dirac theory.

Measurements by Lamb & Retherford (corrected results by Grotchian in 1928)

separation
in the hydrogen
line
H₂: $n=3 \rightarrow n=2$

II then sheet was revised in systematic
error by Robisco (1968) and
further revised by Robisco & Shyne (1970)

in 1947 was first to demonstrate and measure accurately the $25\frac{1}{2} - 2\frac{1}{2}$ shift in hydrogen. Then experiments were continued in period 1947-1953 and then final result was

$$DE = 1057.77 \pm 0.10 \text{ Mc/sec.}$$

Experiment repeated by Holmberg & Coxon (1966)^{II} who are quoted (as the) analysis of the experiment / Holmberg & Slyn (1970) led to latest experimental result

$$DE = 1057.88 \pm 0.06 \text{ Mc/sec.}$$

Theory developed by

(non-relativistic) Bethe (1947)

$$\rightarrow 1040 \text{ Mc/sec}$$

(relativistic) Trull & Lamb, Fink & Weisskopf (1949) $\rightarrow 1052 \text{ Mc/sec.}$
(6 Mc tolerance)

Salpeter (1953) revision more accurate

treatment Coulomb field + approximation

4th order calculation

$$\rightarrow 1057.2 \text{ Mc/sec}$$

($\pm 1 \text{ Mc tolerance}$)

Very quoted 4th order approximation and more accurate treatment Coulomb field

Loggner and Fink & Yennie (1960) $\rightarrow 1057.70 \pm 0.15 \text{ Mc/sec.}$

More accurate 4th order calculation

Log Soto (1966) led to value $\rightarrow 1057.56 \text{ Mc/sec}$

By 1970 experimental value showed real discrepancy.

Applequist & Brudvik (1970) found mistake

in Soto's 4th order calculation $\rightarrow 1057.91 \pm 0.16 \text{ Mc/sec.}$

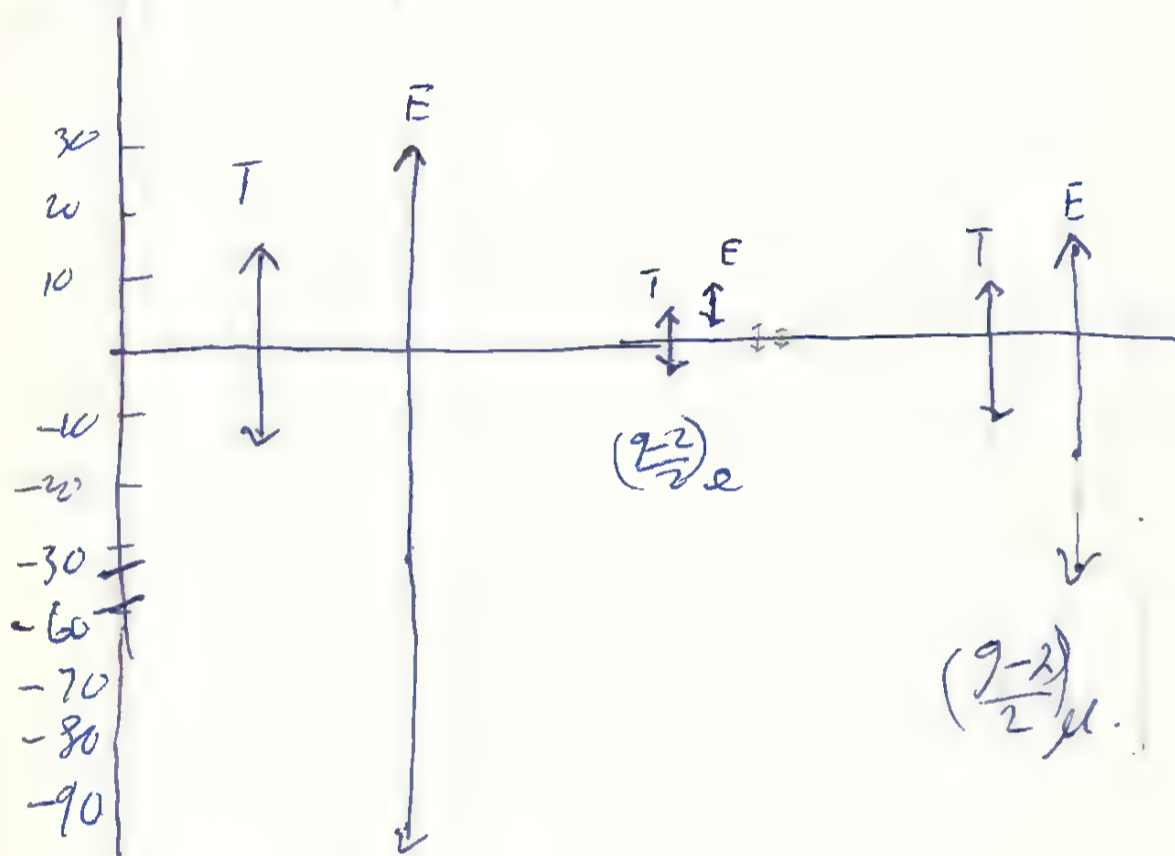
Latest value quoted in Lortz, Rosenmann & de la Harpe review (1972) is $1057.911 \pm 0.012 \text{ Mc/sec}$

accuracy pp.m

	Theory	Expt	D(Expt-Theory)
Long	± 12	± 60	-31
$(\frac{9-2}{2})_e$	± 2.2 (± 0.6)	± 3.5 (± 0.2)	$+5$ 0
$(\frac{9-2}{2})_\mu$	± 10 (± 13)	± 27 (± 27)	-13 (-26)

(1977 values in brackets)

74 series



Long

(2) Anomalous magnetic moment of π^0 electron

First deduced from measurement of hyperfine structure in hydrogen & deuterium by Nafe, Nelson and Rabi (1947).

Isidor (1947) suggested discrepancy between theory & experiment in π^0 experiment was due to ~~anomalous~~ an intrinsic magnetic moment for the electron.

Kusch & Foley (1947) and (1948) tested Breit's suggestion by measuring Zeeman splitting of levels in Gallium — confirmed Schwinger's (1948) calculation of anomalous moment due to radiative corrections.

By 1952 value of $\frac{g-2}{2} = 0.001146 \pm 0.00012$ Baker's value
 confirming Karplus & Kroll's calculation. (2 + $\frac{1}{2}mc$)
(Tweng, Modell & Kusch (1952))

But Franken & Liders (1957) found a value
 $0.001165(11)$, much too high for Karplus & Kroll.

This led to Sommerfield and Potemkin's recalculation of Karplus & Kroll's result in 1957.

Measurement experiments on free electrons (using rotation of polarization of beam of electrons by laser precession in a magnetic field) was initiated by Louisell, Pidd & Crane in 1954, and repeated by Schupp, Pidd & Crane in 1961 who found $0.0011609(24)$. This experiment had even some order of 10^4 order correction so new experiment recalculation by Wilkinson & Crane in 1963.

* Most accurate measurement is due to Schmidt
et al (1977) observing spin flips on a
single electron trapped in a magnetic
torque.

value obtained for electron anomaly is

$$0.0011596524 \pm 0.2$$

Result of Wickham & Crane was $.001159622(27)$
 in good agreement with theory
 but in 1968 Rich re-evaluated the W-C result
 and got a value $.001159549(30)$
 which was 3 standard deviations too low.
 So experiment was repeated by Rich & Wiley
 in 1971. They obtained $.001159657.7 \pm 3.5$
 which could now test the 5th order
 calculations to the anomaly (which are of order 11 ppm)
 Granger & Ford (1972) re-evaluated R & W
 value to give $.001159656.7 \pm 3.5$
 They also created W & C result and brought
 it into line with the accurate W & R
 result (acknowledged in Wiley & Rich
 1972 RMP review article).

Theory developed by

Schwinger (1948) $.001161$ Bethe & Goldstone
 to 2nd order

Karflor & Kroll (1950) $.001145$
 (1st & 4th order calculations in Q.E.D.)

corrected by Sommerfeld (1957) } $.0011596$
 Rostermann (1958) } (close to Schwinger's
 Kroll (unpublished) } old value)

6th order corrections calculated by present
 group.

Levine & Wright (1973)

$.001159651.9 \pm 2.5$
 correcting an earlier calculation of
 $.001159655 \pm 2.$

* Prof Farley remarked on
presenting these results in January 1975
at T. C. seminar
"How does the mean T_e
understand and a confidence
theory"

latest theoretical value for $(\frac{1}{2})_u$ is
quoted by Calmet et al. (1977) as
 $0.001165920.6 \pm 12.9$

Best theoretical value for $(\frac{1}{2})_e$ is given
by Calmet as
 $0.001159652.4 \pm 0.6$

Probably most reliable calculation is
by Cvitanovic & Kunoshita (1974)
who obtain $\cdot 001159651.7 \pm 2.2$
(compared with expt $\cdot 001159656.7 \pm 3.5$)

Note Redness correlations would affect both significant figures
anomalous magnetic moment of Muon

latest measurement by Bailey et al (1975)
 $\mu_B \left(\frac{g-2}{2} \right)_\mu = \cdot 001165895 \pm 27$

who claim is $\cdot 001165908 \pm 10$
(includes 73 ± 10
from d_μ (Redness).)

x

This example suggests the total view
that novel predictions need not be
temporally novel and also stresses
the importance of quantitative prediction
in assessing theories
cf example of classical celestial mechanics
and the calculations of Hylleraas and
later for Pekeris and Kunoshita on
the ground state of Helium

A Bayesian account of how quantitative
predictions affect subjective probabilities
of theories is given by Redhead
in his paper "The Logic of Comparative
Theory Evaluation".

† A power series in λ which is convergent
for any value of λ is absolutely convergent
for any smaller of λ .

* note asymptotic expansion does not fix
the corresponding function uniquely —
Byron shows extra assumptions may be
needed for this.

4 The Nature of the divergences in perturbation theory

Here are two quite separate questions

- (1) are the renormalized quantities themselves finite (i.e. exist) and are not just a divergent sum of finite terms?

The answer is not known for complicated theory like Q.E.D. but model calculations by

Hellmuth and Hunt (1953) & Hunt (1952) for $\lambda\phi^3$ scalar theory show renormalized

series is not absolutely convergent. ~~It~~

(no of graphs of order n is $\sim n^{n/2}$ and

contribution of each graph is $\sim 1/n^2$

So series behaves like $\sum \lambda^n \frac{n^{n/2}}{n^2} \sim \sum \lambda^n n^{n/2-2}$

Defect in this argument is that the n^{th} order term in this series could be conditionally convergent to zero by cancellation of signs - very difficult to investigate - discussed by Riddell (1953)

Probably series is asymptotic

(i.e. $f(z) = \sum a_n z^n + b_n z^{-n-1} \sim \sum A_n z^n$ for limited region of $\log z$.

and $\lim_{z \rightarrow 0} \frac{f(z) - \sum_{n=0}^N A_n z^n}{z^N} \rightarrow 0$ for all N .

So each partial sum approximates $f(z)$ *
"more closely than" z^N as $z \rightarrow 0$.

Typically error involved is smaller than last term calculated, but after a while

* Note recent work by Gellman & Jaffe' (1969-1972)
who solved (2+1) dimensional theories with
 ϕ^3 , ϕ^4 , $\bar{\psi}(x)\phi(x)\psi(x)$ without perturbation
series. Infinities appear in the exact
solutions just as in the perturbation theory
so presumably it is not perturbation theory
which is at fault.

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this last term starts to rise, and series
diverges as $n \rightarrow \infty$.

There are two arguments for asymptotic nature
of expansion

(a) Dyson (1952) claims that if every $e \rightarrow ie$
the series cannot be expected to converge
or indeed to approach to "a well-defined
function" due to the fact that in such a world
refusal of opposite charges would
lead to an "explosive denaturation"
of the vacuum by spontaneous polarization.

(b) Hurst (1952) argues "excellent agreement
between experimental results and theoretical
calculations would indicate that
the series is in fact to be understood
as an asymptotic expansion about its
singular point $\lambda = 0$ ".

(2) Do the renormalization constants exist?
for exact solution of renormalized
interacting fields. \times

Kallen (1953), Redmond (1958) argue
renormalization constants may actually
be finite and appear infinite because
the relevant functions are not analytic
at $e=0$.

e.g. $e^{-e^2 L} \approx 1 - e^2 L + \frac{e^4 L^2}{2} - \dots$

as $L \rightarrow \infty$ L.H.S. $\rightarrow 0$ and each term
in perturbation expansion is apparently infinite.

Considerable light on the "defining" and analysis
they has been thrown by the work of Haag (1955)

Haag's theorem shows that under rather general
restrictions sets of operators referring to
free fields and to interacting fields cannot
belong to equivalent representations of the
canonical ^{equal time} commutation relations (C).
Consequent to connected by a unitary transformation.

This implies that Heisenberg's U operator for
finite times which links the Heisenberg &
interaction representations does not
exist. As Porter (1963) puts it:

"With this fact in mind the occurrence
of formal divergences in the theory is
to be expected and should in no way
surprise us". Roman (1969) comments:

"We may now wonder why, in spite of
its nonexistence, the interaction picture
works, at least in perturbation theory
to reasonable results. The 'Hypocrite' resembles,
in a sense, the noncommensurate manipulations
of ordinary point-mechanics when
one often deals with not recorded operators
and non-normalizable states, pretending that
the structure from which one deduces sensible
results exists. Of course, this always comes
a point when we must realize the inadmissibility
of the manipulations, and the emergence of a
nonphysical result. It is for the physicist to
adapt, eventually, a mathematically rigorous framework."

To circumvent Haag's theorem, we
have to allow the dynamics to select
the appropriate inequivalent representation

The evidence of non-equivalent representations is associated with the fact that the dimensionality of the Hilbert space associated with an system with an infinite number of degrees of freedom is non-countable, i.e. the Hilbert space is non-separable.

In the late 1960's a new formulation of field theory was introduced by Schwinger with his 'Method of sources' (1969).

Schwinger allows his actual fields to interact with an unquantized source field whose strength is ultimately allowed to go to zero. The source field is expected and to 'probe' the structure of the actual fields. Using methods of functional analysis S. has given a new formulation of quantization theory which, he claims, avoids the ambiguities of the 'canonical' approach, and once and done provides a reformulation of conventional field theory as ~~integrated~~ ^{integrated} body to an 'official' to particle physics which S. claims to be intermediate between and superior to either field theory and S-matrix theory. (cf. Schwinger: Particles & Sources 1969). It does with field theory to physical explanation of space & time, but it is not a ~~unified~~ ^{unified} theory - like S-matrix; it is phenomenological in its explanation of the actual physical system. S. sees his method as a decidedly the correct degree of approach ('curious one apparently more physical than Field's').

* ~~Forget & Sornikier (1973)~~

~~"It seems to us very unlikely that
parton is really just particles.
... a parton will be resolved
even further into yet another hierarchy
of constituents."~~

(4) The Analytic S-Matrix

1. Heisenberg introduces S-matrix theory

The research programme of the analytic S-matrix derives from two strands

- viz the S-matrix, (1) a thesis about what a fundamental theory of elementary particles should report to
- (2) a new non-perturbative method of calculating the S-matrix.

Heisenberg (1943) introduced the S-matrix or scattering matrix as the fundamental entity of interest by asking two questions. (original Furter on S-matrix explicit basis Heisenberg 1937 on nuclear physics)

(1) If a "complete" theory should involve a fundamental length what pattern of elementary processes might be expected to survive in such a "complete" theory (cf. Einstein's attitude to relativity as having "survived" beyond a suspect (due to photon effects) classical electrodynamics-magnetism described by Maxwell's equations).

(2) Should not a theory restrict itself only to what can actually be observed (cf. his original note of objection for introducing matrix mechanics).

Heisenberg suggested answer to (1) and to (2) ~~in view of fundamental length~~ was the formulation of the S-matrix

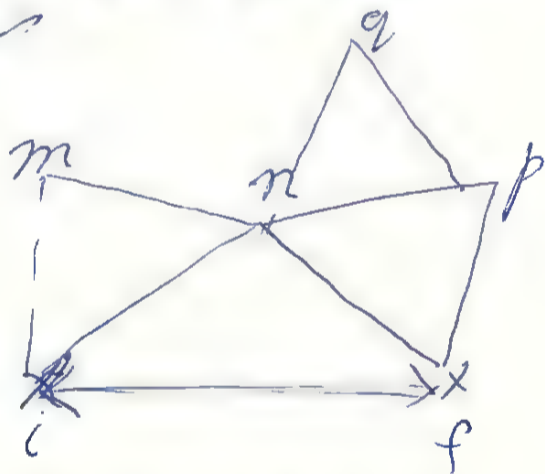
- which would comprise two sets of information
- (a) scattering ^{or reaction} cross-sections derived from scattering transition amplitudes from an arbitrary initial to an arbitrary final state.
 - (b) Bound-states and resonances (short lived unstable particle states) would be related to singularities in the S-matrix, at possibly unphysical values of the arguments. The idea here is that anomalies or "bumps" in scattering cross-sections are connected with formation of unstable but relatively long-lived "complexes" composed of the incoming particles.

2. Non-perturbative calculations of the S-matrix

The success of Q.E.D. is due to the applicability of perturbation theory which is related to the small value of the fine structure constant ($e^2/\hbar c \approx 1/137$) i.e. to the weakness of the electromagnetic interaction. For nuclear physics the particle interaction via the strong interaction which involves the perturbative approach (contrast e.g. the atom bomb with chemical high explosive) is to apply field-theoretic approach to calculate S-matrix required wherever approximation.

For example we could consider a limited number of virtual particles in an arbitrary number of states (Tamm-Dancoff approximation) or an arbitrary number of virtual particles in a limited number of states (Tomonaga approximation). But no satisfactory method of dealing with renormalization could be found, and no adequate account of $\pi\pi$ scattering was achieved. Success in accounting for features of low energy $\pi\pi$ scattering (the 3-3 resonance in the ρ -wave for example) resulted from the Chew-Low-Wick model which involved a quite different approach and involved expressing the scattering amplitude for a real (or virtual) physical process in terms of scattering amplitudes for all "real" processes. ~~Before~~ ~~which~~ ~~could~~ ~~begin~~ ~~correct~~ with both the initial and final states.

We repeat the notation schematically as follows:



It was soon demonstrated (Adams (1955)) that the Chew-Low model was an example of a dispersion relation and was connected with analytic properties of the S -matrix.

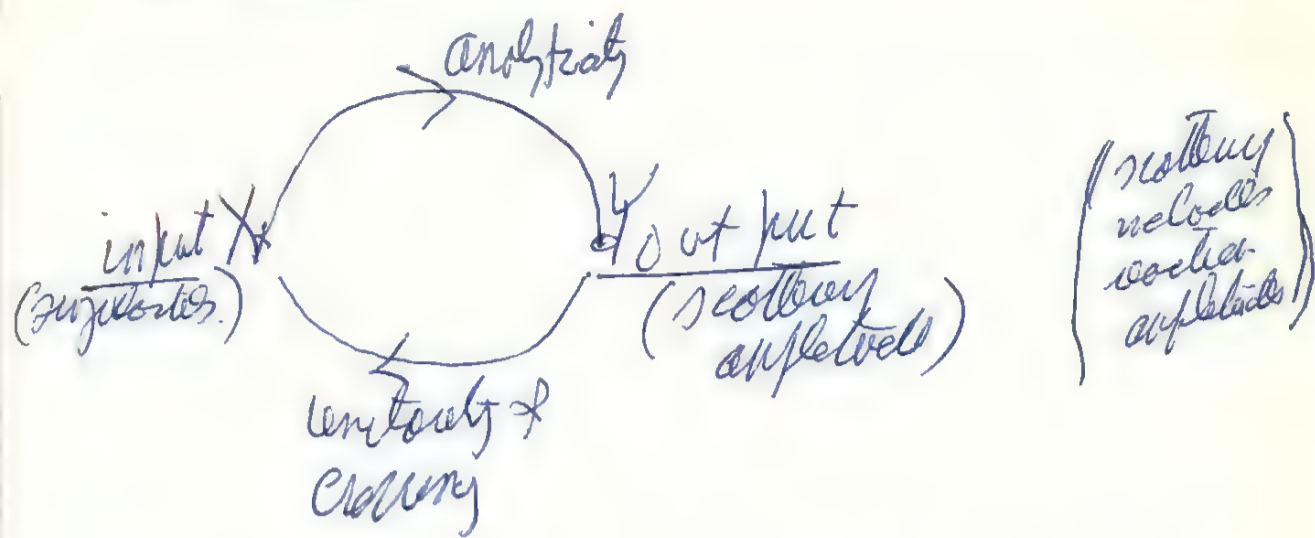
3. Dispersion Relations

The dispersion relation approach to calculating the S -matrix involves the following sequence of ideas.

- (a) We consider the S -matrix elements as function of energy (and other variables) and we now allow energy to assume complex values.
- (b) We assume S -matrix is an analytic function, except for certain singularities (By Liouville's theorem, a bounded analytic function with no singularities is necessarily a constant).
- (c) We use Cauchy's ^{theorem} to relate scattering amplitudes to the singularity structure (position of singularities and behavior of the function as the neighborhood of the singularities is approached at poles and branch cuts).
- (d) We use unitarity & crossing principle to locate part of the singularity structure (see below).
- (e) We assume there are no other singularities than those demanded by unitarity & crossing (theorem of maximal analyticity of first kind) or the Mandelstam Conjecture.

* (A) A principle of Maximum strength
is used to eliminate differences
in strength of couples, constants.

(d) We now have a coupled feedback situation



e.g. we suppose analytical. $Y = X$
velocity $X = Y^2$

Soln here is $Y = 0$ and 1 is non-unique

(e) We look for possible ambiguities in soln of equations and seek to remove them by a principle which eliminates certain singularities. This is achieved by principle of reversal. A variant of second kind which is expressed by considering complex momentum as well as linear momentum as a complex variable (as is suggested by "Every pole is a Regge pole, & the Regge trajectory in complex angular momentum plane").

So we analyse model as causal anti-sym. soln must be analytic under reflection in upper - lower plane. The $Y = 1$ soln at $Y = 0$ is ambiguous. result $Y = 0$. *

4. Singularities, unitarity & crossings

We dedicate briefly the steps which build unitarity, which requires the conservation of probability, with the regularity structure

(a) Consider a function $f(z)$ which satisfies the Schwarz reflection principle

amplitudes satisfy $f(z^*) = f^*(z)$, scattering principle of the type.

(b) Singularities in such a function are on the real axis are identified by the appearance of an imaginary part for $f(z)$ in the neighbourhood of the real axis

$$\text{become if } f(x+i\epsilon) = u + i v$$

$$\text{then } f(x-i\epsilon) = u - i v$$

So there is a discontinuity of $2iv$ in crossing the axis, which indicates a branch cut, the "threshold" for which is a branch point.

Then at $x=a$ poles are also identified by writing

$$f(z) \sim \frac{\beta}{z-a} = \beta P\left(\frac{1}{z-a}\right)$$

$$f(x \pm i\epsilon) \sim \frac{\beta}{x \pm i\epsilon - a} = \beta P\left(\frac{1}{x-a}\right) \pm i\pi \delta(x-a) \beta$$

So again the imaginary part identifies the position & residues at the pole.

(c) If we take β for a scattering amplitude then β for forward scattering is connected with the definition of partial waves for the incident beam (of the imaginary part of a refractive index for example as an absorption coefficient)

But by comparison of probability (and the
 escape probability comes in) the fraction
 of particles from incident beam is related
 to rate at which particles are emitted
 into all possible reaction channels
 representing scattering or production processes.

This situation generalizes to the case
 of non-forward scattering and serves to
 identify branch points on the real axis
 such thresholds or which a new
 reaction channel becomes energetically
 possible. It also the reaction
 channel involves the formation of a
 single particle leads to the "degenerate"
 case of S-function for the imaginary
 part of the amplitude $i0$ to a
 pole - referred to as a particle pole.

Reviewing the above chain of argument
 it becomes plausible that we have
 the following chain of connections

Reaction amplitudes \rightarrow Im. Scattering amplitudes
 \rightarrow singular structure
 of particle poles &
 normal thresholds
 branch points.

So here we have the sought-for connection
 between transition amplitudes and
 part of the singular structure.

In the same way Cutting states that
 the scattering amplitudes may be related
 to order by analytic continuation to

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unphysical poles of energy & momentum transfer (or support zero of 2-particle cluster scattering). Without new forces singularities in these closed channels which appear as in the direct channel as singularities at unphysical values of the energy & momentum arguments.

5. Analyticity & Causality

The question now is how do we know there are no other singularities than those enforced by causality & energy, e.g. singularities in the off the real axis at complex values of the arguments.

The first approach to this problem is to try and look analytic with causality after the fashion used in deriving dispersion relations in optics (Kramers-Kronig relations) which connects the real and imaginary parts of the refractive index, or similar results in the theory of electrical circuits etc.

These classical results depend on the following mathematical result.

Consider some physical system which exhibits a linear causal response $H(t)$ to an input $G(t)$. via a response function $L(t)$ where

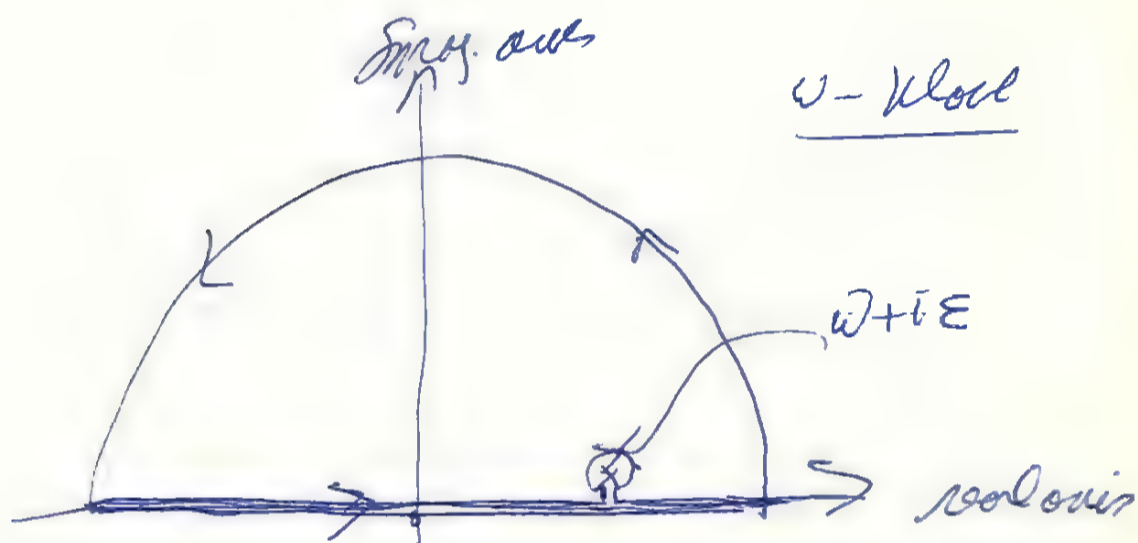
$$H(t) = \int_{-\infty}^{\infty} L(t-t') G(t') dt'$$

* theorem needed two ways.

If $h(z, w)$ is analytic function of z for all values of w on the path of integration then integral

$$f(z) \equiv \int_{\gamma} h(z, w) g(w) dw$$

is an analytic function of z so long as the integral converges absolutely.
($g(w)$ need not itself be analytic)



The causality condition is $L(\tau) = 0$ for $\tau < 0$.
 We are interested in properties of the Fourier
 transform

$$\tilde{L}(\omega) = \int_{-\infty}^{\infty} L(\tau) e^{i\omega\tau} d\tau \\ = \int_0^{\infty} L(\tau) e^{i\omega\tau} d\tau$$

This is an analytic function of ω in the
 upper half-plane. (assuming $L(\tau)$ is
 polynomial bounded in the upper half plane)

$\tilde{L}(\omega)$ is related to forward scattering amplitude
 for S.H. wave of frequency ω in optical
 application and this in turn is related
 to the reflection index

So $\text{Re } \tilde{L}(\omega)$ relates to dispersion
 $\text{Im } \tilde{L}(\omega)$ relates to absorption

Dispersion relations connecting these two
 quantities can now be established as

$$\tilde{L}(\omega + i\varepsilon) = \frac{1}{2\pi i} \int_{-\infty}^{\infty} \frac{\tilde{L}(\omega') d\omega'}{\omega' - \omega - i\varepsilon} \quad \square$$

$$\text{where } \text{Re } \tilde{L}(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{\text{Im } \tilde{L}(\omega') d\omega'}{\omega' - \omega} + \frac{1}{2} \text{Re } \tilde{L}(\omega)$$

$$\therefore \text{Re } \tilde{L}(\omega) = \frac{1}{\pi} \mathcal{P} \int_{-\infty}^{\infty} \frac{\text{Im } \tilde{L}(\omega') d\omega'}{\omega' - \omega} \\ = \frac{2}{\pi} \mathcal{P} \int_0^{\infty} \frac{\text{Im } \tilde{L}(\omega') \omega' d\omega'}{\omega'^2 - \omega^2}$$

If we have $\text{Im } f(-\omega) = -\text{Im } f(\omega)$ causality condition
 which holds in the
 optical case.

To pursue the idea in QFT we can try to derive analytical properties from microcausality as enforced in the canonical equal time commutation relations for fields

$$[\phi_1(x_1, t), \phi_2(x_2, t)] = 0$$

if $(x_1, t) \rightarrow (x_2, t)$
is space-like
so two parts cannot be
connected by a light signal

A difficulty is that we cannot rigorously derive analytical results in sufficiently large domains to exploit the full dispersion relations approach. Some partial results can be obtained e.g. for π -N scattering fixed t dispersion relations are provable for $0 \leq -t \leq 18 m_\pi^2$. We want now more complete information about analytic properties in all variables (e.g. s and t for 2-body scattering)

6. The Mandelstam Conjecture

Another approach is to examine the analytic properties of particular Feynman graphs and try to "infer" analytic properties of the full amplitude.

Mandelstam investigated some 4-2 order Feynman diagrams and showed that a particular representation (as a double dispersion relation) was possible.

In 1958 he adopted a bold conjecture. Instead of trying to derive analytic properties from field theory, let us be guided by the successes of such dispersion relations that can be derived (e.g. pion scattering off N system) and also use what we know from consideration of Feynman graphs and now make a Conjecture as to what the analytic properties of the amplitude are. The conjecture is for the full amplitude.

The Mandelstam Conjecture as formulated in his 1962 review article reads:

"The scattering amplitude is analytic in all its variables except at those points where singularities arise as a consequence of the unitarity condition."

In his 1958 paper Mandelstam went on to argue that the singularities described by unitarity would permit a specific representation — the Mandelstam representation. The latter assumption, although very fruitful

* On London's ornamental admittance
field theory - the details of field
theory notes from the 1930 - of
Peck & London

turned out not to be true in Perturbata theory (Randelstam, 1959) - for
was Randelstam able to prove his
representation to be generally valid from
oscillations field theory even for cos.
wave perturbation theory suggested it
might hold (Randelstam v.c. 1960)

However the Randelstam representation
was found for non-relativistic particles
scattering (2 Yukawa interactions)
by Blankenbiller, Goldberger, Khuri
and Treiman in 1960 and by Kessler
in 1959 using his method of
Complex angular momentum.

Randelstam himself regarded his
conjecture as just that a
conjecture about what field theory
should behave. He did not
subscribe to the no need of
his idea by Chew, Frautschi, Stapp
& others. In his 1962 review
he claims (1) P. notation contains
less than can actually be measured
(2) Only half amplitudes
or phases "are rather
artificial"

He does that however relations could
actually reflect field theory
goes back to Gell-Mann (1956
Pöschel's experience)
But Randelstam's ideas were taken
up enthusiastically by Chew, Frautschi,
Stapp & etc and led to the

* This idea can actually be traced back
to Koenig (1946)

note how Foreman had
enabled physics to deal
with non-analytic
functions - check now
reverts to now dot locally
we should only consider analytic
functions.

idea of an S-matrix theory quite independent of field theory in which the Mandelstam Equations would now play the role of a postulate.*

The question whether this postulate could be derived from some local field theory was considered irrelevant.

In the development of our new S-matrix theory two points of view about the status of the analyticity postulate emerged.

(1) Chew emphasized the purely mathematical aspect. In his 1966 book *The Analytic S-matrix* he writes "In a deep sense physics is based on analytic functions. It is pointless to seek a logical origin for these circumstances. Physical theory cannot be based on logic; it is always a matter of guesswork based on observation of nature. One cannot for example, argue that it is logical for classical mechanics to be expressible through second order differential equations. This simply is the scheme that works."

In his 1962 review Chew writes "the fundamental paradox ... is of maximum smoothness ... and a natural mathematical definition of smoothness lies in the concept of analyticity."

* ~~Lagarias~~ Jagannathan & Staff are concerned to learn normal analytic structure in the physical region with their principle of macrocausality - this may be deducible from analyticity alone or may be an extra requirement.

At all events a principle of maximal analyticity is required to extend the present domain of analyticity covered by the macrocausality principle.

Note also work of Zeeman (1964) who uses causality to derive the Lorentz group, but this is sufficient, not necessary condition for macrocausality to cover well to current with Lorentz group aspects of Zeeman's work.

That Chen stresses on one used is connected especially with the "Gelfand structure" this is what Rindelman effectively criticizes in his 1962 review.

- (2) Stapp ~~is~~ has tried to link ergodicity with a macrocausality principle - causality may be allowed to fail over short space-time intervals - indeed to claim microcausality may actually be inconsistent with axiomatic S-matrix theory (1962) (Gogolnitzer and Stapp (1969))
 * derives macrocausality & analytic structure in physical region
- Stapp regards S-matrix theory as expressing a "prognostic attitude towards physics" & QM and does not offer ^{entirely} to show Chen's view of the priority of purely mathematical considerations.

7. The Chen-Rindelman Relevance Strategy

Effectively what the note to Chapter 7 states is as follows.

(a) Rindelman derives a property (of ergodicity) by considering an approximation model of field theory (10.4th order perturbation theory)

(b) Rindelman expects this property to be true of complete theory

(c) Chew now revisits the conjecture as being "model-independent" by fiat and takes it as an ~~axiom~~ axiom for a new theory which may or may not be equivalent to (i.e. a reformulation of) the old theory.

We represent this sequence schematically in the following way.

original theory approximation ..

$$T + A \rightarrow T_1 \rightarrow P \text{ (approx C)}$$

approximate theory proper
(model 2) & the
 model

→ $T'(P)$
new theory with
 P incorporated as an axiom.

So in our case

T is R.Q.F.T.

A is Feynman perturbation theory

T_1 is a class of Feynman diagrams

P is explicit proper & other diagrams.

C is dispersion relations involving double quantities which is verified separately

$T'(P)$ is QED with explicit S-matrix theory.

✓ The source of the C. P. P. argument is
that the Nyquist contour encloses
no poles and is regular at ∞
in complex plane - i.e. and
may need substitutions which introduce
additional singularities into
dispersion relations. Removal of C. P. P.
poles is equivalent to an assumption
about asymptotic behavior by assuming
all phase shifts at high energy (cf.
Levinson's theorem)

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Another example of the heuristic strategy
would be Gold-Mann's current
algebra (1962) ^{in which} ~~the~~ ^{the} ~~current~~
properties of currents are derived from
a fortetator model - effective. The
quark model is made model-
independent by just not taking as
the starting point for constraining
all subsequent theories.

8. C. D. D. Ambiguities

The Modelistam representation led to
the possibility of formulating partial
wave dispersion relations. But
it turned out that the resulting
integral equations did not have
unique solutions - in particular
an arbitrary number of poles
could be introduced into the
pole and the equations would
still be satisfied. This
ambiguity was already
known from the study of
the Chew-Low model and
is known as the Castillejo-Dalitz-
Dyson Ambiguity (1956) (abbreviated
C. D. D.). * The ambiguity was
limited to partial waves $\ell=0$
or 1 (2 Fierz and Landau)
and the possibility of removing the

* The reason why the Ryzh poles
are ~~considered~~ regarded as complicated,
i.e. dependent on degree is that
the location of the poles depends
on the strength of the interaction
(which controls the shape of the
Ryzh Trajectories in the T -Plane)
The C.D.N. poles are fixed
independent of the strength of
the interaction.

WS

ambiguities, led to the idea of a
bootstrap theory of the heavens.

9. The Chew-Frautschi Bootstrap

Chew & Frautschi (1961) sought
to eliminate the C.P.N. ambiguity
by using Regge's ideas about
angular momentum.
They introduced a bootstrap
mechanism analyzing of the
second level which says
that all forbidden poles and
Regge poles i.e. determined by
bootstrap analytic continuation in
J from the regular high
angular momentum poles.
C.F. interpret this as
a bootstrap democracy, the
arbitrary C.P.N. assignments
having been eliminated. *

How still raised the question of
whether all arbitrary parameters
could be eliminated from the
theory. Chew & Frautschi (1962) also
introduced a bootstrap
principle to fix the overall strength of

interactions ^{on a separate occasion} they may in fact not be required, but appear to be interrelated experimentally.

The first object of the Lodship is to have no arbitrary parameters except a dimensional constant to fix the scale of the Lodship masses.

In general there are now 3 possibilities

- (1) There are several sets of particles that satisfy the Lodship
- (2) There is no set of particles that satisfy the Lodship
- (3) There is a unique set of particles that satisfy the Lodship and there are the particles derived in Nature.

The last possibility ~~was~~ is also called
may call it Chen-Frankski
Hypothesis.

examples of partial bootstraps

(1) $\rho = \pi \pi(\rho)$

Two perm "enclaves" a ρ which produces
an intervention which leads to π
to form the ρ

of Chew & Rosenblum
Chew & Frantschi
Zachary & Zeman

(2) $N = \pi N(N)$

$\pi = N N(\pi)$

In this model π & N could both be
bootstrapped

(3) The reciprocal bootstrap

$N = \pi N(N^*)$

$N^* = \pi N(N)$

of Chew,
Abers & Zeman

More generally we should write

$\{N, N^*\} = \pi N(N, N^*)$

Some of partial bootstrap schemes
are pretty rough, out from experimental
values of masses & widths by factors
of 2 or 3.

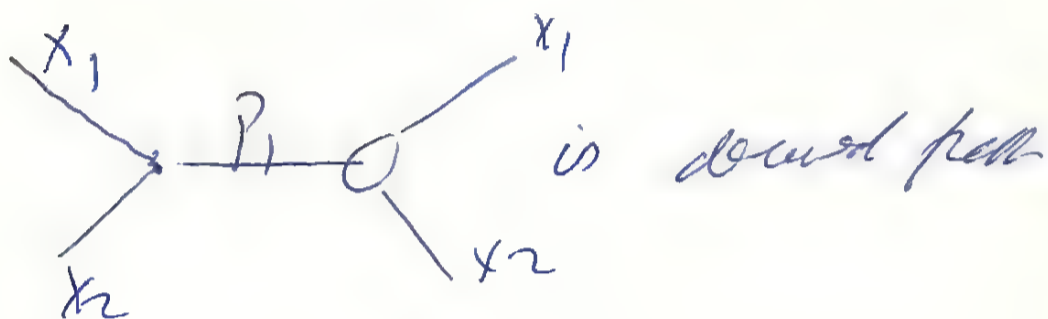
In general we write

~~$\{x_1, x_2, \dots\}$~~

$$\{p_1, p_2, \dots\} = x_1, x_2, \dots, (\phi_1, \phi_2, \dots)$$

Composites constituents "exchange"
particles.

Example



Some people may object or may object
reactions so we can write

$$p = x_1 + x_2 \text{ or } x_1 + x_2 + x_3 \text{ or}$$

The point about the notation is that the
sets $\{p\}$, $\{x\}$ and $\{\phi\}$ are
all the same set, the unique
set of actually existing particles.

$$* \text{ So } \lambda + A = (B + e) + X$$

is not to be interpreted as p
being broken up into $B + e$ by
collision with particle X .

Then leads to some apparent anomalies

e.g.

$$A = B + C$$

and

$$B = A + C$$

So A is part of B and B is part of A

or $A = A + B$, so A is part of itself.

This surely shows the inadequacy of a simple containment model

In fact it is best to think of energy in the modern system as being used to "create" the outgoing particles in a reaction

In this sense there is no anomaly in some examples when they are interpreted in terms of "creating" the energy particles instead of "releasing" what is already there. *

Comparison of Leibniz philosophy with other philosophers

- (1) Leibniz clear states speakers of principle of sufficient reason. (1683)
"Nature is as it is because there is the only possible world consistent with itself"

Two uses of Leibniz

(a) Many possible worlds - existing world is chosen by God as best possible

used

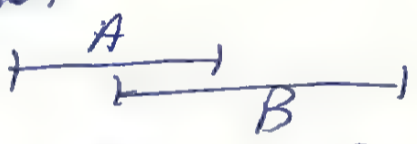
(1) even *quodlibet* is rationally determined
(cf Russell's interpretation of
Leibniz's secret philosophy).

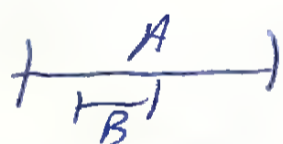

clearly clear borders from Leibniz
also color that nothing is rational
is arbitrary.

(2) *Unosopos* does everything abstract
contains every other substance.

But A's place view is essentially
a containment model.

Contradictions are avoided by
formulation seeds contain portions of
all seeds in place of seeds
contain all seeds
e.g. 2 sets A & B not each enclose
subsets of each other



But if  then 

is impossible.

Also for *Unosopos* the
substances are immovable
- i.e. it is a form of determinism

The criticism is not done to the
view that substances can change.

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these form e.g. Thales, Anaximenes,
Anaximander and in particular
Heraclitus

Anaxagoras is mentioned by Empedocles,
Leucippus & Democritus all of whom
derive from the Ionian tradition
to Heraclitus.

(3) Prologos with Eratosthenes philosophers
not as Heraclitus & Anaxagoras for
has started by Capra in his book
The Tao of Physics

(4) Prologos with Whitehead for been
started by Stapp (1971). The book
is a well philosophy of introducing
processes - refers to Whitehead's
process and reality!

Shortcomings of the tortoise

- 1.) It makes life very difficult for physicists
- 2.) Tortoise leads to no is impossible to satisfy - we may have to include all particles it does
- 3.) Idea may be untenable, and is unscientific due to 'enormous mathematical complexity' of a full tortoise.
- 4.) Tortoise does not include the effects of matter - thus claims these particles are connected with process of measurement, so should be treated differently.
But what about the other factors - the mind of the physicist?
- 5.) Clear makes some useful metaphysical claims. It says a complete tortoise would demand for self-consistency "confronting the elusive concept of measurement and possibly even of consciousness".

* Report of Susskind (1973)

"It seems to us very unlikely that partons are really point particles ... a parton will be resolved even further into ^{yet} another hierarchy of ~~components~~ constituents".

The Ultimate Nature of Matter

1. The Bootstrap Picture

Formally we write

$$X_1 = \begin{cases} X_1 \\ X_1 + X_2 \\ X_1 + X_2 + X_3 \\ \vdots \end{cases}$$

$$X_2 = \begin{cases} X_2 \\ X_1 + X_2 \\ X_1 + X_2 + X_3 \\ \vdots \end{cases}$$

so that each particle X_i may be represented as composed of other particles in many different ways corresponding to all the competing reaction channels to which the particle is linked.

2. The Bootstrap Fundamentalism

The bootstrap equations have a solution in form

$$X_1 = \phi_1 + \phi_2 + \phi_3 + \dots$$

$$X_2 = \phi_1 + \phi_2 + \phi_3 + \dots$$

in terms of a set of fundamental dyons ϕ_1, ϕ_2, \dots o.s. hadrons are explained in terms of quarks at a "deeper" level of structure.

These equations may be understood in simple containment sense, hadrons have been interpreted in terms of ~~resonances~~ rearrangement of "condensing" quarks. The end lead to an infinite regress. *

3. Maximanderon Fundamentalism

Fundamental is something different from ordinary matter (cf. the ^{apocryphal} ~~Apocryphon~~ or Unaffiliated being of Maximander)

Schematically we write it for lack of as

$$\begin{aligned} X_1 &= X_1(F) \\ X_2 &= X_2(F) \end{aligned}$$

is all possible, or explained as "excitations" of a single particle, the unified field F .

Mathematics (M) is her brother to Nuclear Physics gives the analogy of particles as knots on a string.

- cf. Hawking's Unified Field Theory.

4. Mathematical Atomism

Analogy between Plato's story in Timaeus of building regular solids from two sorts of triangles and the $SU(3)$ symmetry patterns being built up out of simple "triangular" excitations.

4.

Conclusions1. The Structure of Scientific Theories

Our methodology of heuristics comprises features from several sources.

A From Kuhn it accepts paradigm shifts but only on the grand scale.

B From Lakatos it accepts hard-core & protective belt.

C From Popper it rejects normal science and also the working of the positive heuristic as "dull" science.

D From Toulmin it borrows the concept of a unit of variation in an evolutionary approach to the growth of science.

E

The unit of variation is identified with a micro research programme.

2. Corespondence Relations

The relation between successive research programmes (micro & not) whether a paradigm is one of corespondence. which explains the conservative element in new theories which borrow structure from old theories. The features of corespondence have been analysed under the notion of a directional shift followed by a 'switching' in the direction indicated.

by a polarizing phenomenon or by a polarizing property of some model of the old theory

3. The Role of Surplus Structure

The role of surplus structure has been emphasized and one way of reformulating and stretching a theory is by altering the surplus structure of some extension of a mathematical model of the old theory. This emphasis on purely mathematical considerations is a feature of modern theoretical physics that is also apparent in the work of Einstein and Dirac.

4. The Floating Model

We have stressed the importance of the computation gap. If an approximate calculation disagrees with experiment we do not know whether to discard the nuclear theory or at the approximation.

In the case of atomic & molecular physics we have some confidence in the underlying theory because there are some solvable problems such as the hydrogen atom or molecule which can be solved very accurately so that predictions really do test the theory not the theory + approximations. We can now argue that if in a more complicated problem (in nuclear physics or chemistry for example) a scheme of approximation

gave results in agreement with experiment then we may believe this approximation has picked out the essential relevant features of some complicated dynamical situation. i.e. we can justify the approximation a posteriori in virtue of its success.

But in particle physics there are no simple solvable problems — we have seen from solution of a one problem always involves simultaneous consideration of many other problems in the spirit of the bookkeeping.

Hence our approximation models are not anchored to any secure underlying reality — in this sense they may be said to float.

For a stronger sense of floating model is that approximation models may also be used which do not agree with experiment — they float at both ends (theoretical and experimental).

But such models are only objectionable if they are not allied with a requirement that the mismatch between the model and the experimental results is describable (theoretically) in a simple way. e.g. in Elliott's $SU(3)$ model in Nuclear physics the broken symmetry is represented by a quadrupole interaction which does not mix different irreducible representations of the underlying symmetry of the harmonic oscillator potential (it is a function of the generators of the $SU(3)$ symmetry).

8. In a sense the bootstrap philosophy of the current would point to a fundamental unfairness for scientific method as we know it. The success of scientific method depends on the possibility of being able to isolate simple phenomena and of being able to disregard the enormous complexity of every real-life situation. The bootstrap philosophy would tell us that in the realm of human dynamics the approach is no longer possible, as a parallel we can think what celestial mechanics would be like if the planetary system was not susceptible to perturbation theory.

The bootstrap philosophy is essentially one of despair and frustration, although I hear himself sees things just the other way around (1970)

"I would find it a curiously disappointing if in 1980 all of modern physics could be explained in terms of a few arbitrary entities — we should then be in essentially the same posture as in 1930 — to have learned so little in half a century would to me be the ultimate frustration."

I hope what I have said has been sufficient
to substantiate ~~the~~ the claim I made
in my opening remarks viz. that
particle physics has exposed or at
any rate ~~highlighted~~ ^{emphasized} some methodological
problems which deserve the attention
of philosophers of science.
